FITS FORMAT FOR PLANETARY SURFACES: BRIDGING THE GAP BETWEEN FITS WORLD COORDINATE SYSTEMS AND GEOGRAPHICAL INFORMATION SYSTEMS. C. Marmo[1], T.M. Hare[2], S. Erard[3], B. Cecconi[3], F. Costard[1], F. Schmidt[1] and A. P. Rossi[4], [1]GEOPS, Univ. Paris-Sud, CNRS, Univ. Paris-Saclay, Rue du Belvédère, Bât. 509, 91405 Orsay, France, chiara.marmo@u-psud.fr, [2]U. S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ, [3]LESIA, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universités, UPMC Univ. Paris 06, Univ. Paris Diderot, Sorbonne Paris Cité , Meudon, France, [4]Jacobs University, Bremen, Germany.

Introduction: The amount of available data is rapidly increasing for planetary investigations and planetary surface research continues to evolve from mostly visual assessment to more automated quantitative analysis.

Both geologists and now more astronomers are involved in mapping planetary surfaces. Geologists, for their mapping and analysis needs, commonly use Geographical Information Systems (GIS). In general, GIS applications excel in data interoperability even though some have historically been anchored to Earth's spatial description. Astronomers, in contrast, are well known for their open and flexible formats and software for quantitative analysis of huge data sets. Unfortunately, the astronomy domain is not accustomed to supporting data for three-dimensional planetary surfaces.

This abstract will describe how Flexible Image Transport System (FITS) World Coordinate System (WCS) [1] metadata can be translated for the planetary domain to allow FITS data to interoperate with GIS applications.

In particular, we will discuss the translation between WCS and Planetary Data System (PDS) and Integrated Software for Imagers and Spectrometers (ISIS) format terminology and an alternative approach to convert FITS into a Geospatial Data Abstraction Library (GDAL) Virtual Header Format (VRT) [2] as a first step for FITS visualization within GIS software.

Why FITS: FITS has been defined for data acquisition and archiving in astronomical observatories and is used for spatial telescope data. FITS is one of the standard formats in the Virtual Observatory (VO), it is compatible with PDS archiving specifications and supported by a large number of open libraries and software tools. The option to use FITS within the planetary domain could be an opportunity to allow more seamless sharing of data across these different domains and potentially homogenize methods from acquisition, to visualization, while giving more chances to optimize data processing.

FITS WCS: FITS WCS representation simplifies the spatial coordinate description with respect to historical terrestrial references. There is no need for oblique projection definitions [3,4] as projection parameters (projection center or reference point) describe the difference between the Mercator and Transverse Mercator or Simple Cylindrical and Equirectangular map projections. There is no need for East or West positive longitude definitions as the pixel conversion in world coordinates is set by a common oriented matrix.

However, if still needed, FITS does offer the possibility to fully describe those same parameters using alternative WCS definitions (meters, degrees, East and West longitude, etc.) [5]. Nevertheless, WCS does not record information about the body shape and orientation, and reference surface. This limitation must be addressed to support surface studies.

PDS/ISIS dictionaries as Mapped to FITS: Table 1 contains the translation between FITS and PDS/ISIS nomenclature for the most popular projections. The conversion between projection parameters depends on projection type, thus as an example, Table 2 gives conversion for cylindrical projections in degrees.

Table 1. Projections

FITS	FITS projection name	PDS/ISIS projection name
SFL	Sanson-Flamsteed	Sinusoidal
ZEA	Zenithal Equal-Area	Lambertazimuthalequalarea
COO	Conic orthomorphic	Lambertconformal
CAR	plate carre	Equirectangular
MER	Mercator	Mercator
SIN	Orthographic	Orthographic
AZP	Zenithal perspective	Pointperspective
STG	Stereographic	Polarstereographic

Table 2. Parameters for cylindrical projections (coordinates in degrees)

FITS parameter	ISIS conversion	PDS conversion
CRPIX1	Samples / 2 + 0.5	LINE_SAMPLES / 2 + 0.5
CRPIX2	Lines / 2 + 0.5	LINES / 2 + 0.5
CRVAL1	CenterLongitude	CENTER_LONGITUDE
CRVAL2	CenterLatitude	CENTER_LATITUDE
CD1_1, CD2_2	1 / Scale	1 / MAP_RESOLUTION

FITS and GDAL: The Geospatial Data Abstraction Library, released by the Open Source

Geospatial Foundation, offers powerful data conversion and processing capabilities. GDAL is essentially a format translation library written in C++ for geospatial raster and vector data [6]. In 2007, the ISIS2 and PDS readers were updated and ISIS3 support was added. Any application which supports the GDAL library can now easily recognize these planetary data formats, including the planet definition, projection parameters, and label information like pixel value offset and multiplier.

Fortunately, GDAL also has support for FITS via the popular CFITSIO library [7]. Next we discuss some of the known issues that should be addressed in GDAL, besides our needed FITS keywords to support geospatial applications. We will also discuss an alternative method to more quickly add GIS support for FITS images using a GDAL-supported detached header.

Known Issues:
Similar to PDS, FITS often stores pixels as a result of a quantization (i.e. conversion from real numbers to integers while maintaining an offset and multiplier value to allow the original range to be recovered). To facilitate analysis, without user intervention, GDAL should apply the defined offset and multiplier values before returning data to the user. FITS images are always stored as signed integers and the supported BZERO and BSCALE keywords (corresponding to offset and multiplier in ISIS) also allow FITS to better support unsigned data range. The CFITSIO library automatically manages conversion between different data types in FITS, but currently CFITSIO rescaling causes overflows with GDAL and has been disabled.

During the conversion from PDS and ISIS, or even TIFF, the GDAL readers do not automatically scale the pixel values and depend on the application to apply these adjustments for the user. By updating this BZERO and BSCALE behavior in GDAL within the FITS format, it would be a good opportunity to address this limitation in the ISIS and PDS readers and possibly offer this dynamic adjustment within all supported GDAL formats.

GDAL Virtual Header:
The VRT format is a verbose XML-based detached header created by the GDAL team. It is a very powerful mechanism to describe diverse images (or groups of images – for example a virtual mosaic). VRT files can simply describe the internal structure of a FITS image but it can also describe the map projection and body size in a standardized "well known text" (WKT) projection string. Unfortunately, the current FITS implementation in GDAL does not propagate all the original metadata into the output VRT file but this will be updated. For FITS VRT examples and conversion tools please see: https://github.com/epn-vespa/fits2vrt.

Shape and orientation keywords: Generally, planetary body shapes and orientations are well defined and standardized by the International Astronomical Union (IAU) Working Group on Cartographic Coordinates and Rotational Elements (WGCCRE). This group reports triennially on the preferred rotation rate, spin axis, prime meridian, and reference surface for planets and satellites which helps ensure that cartographic endeavors are effectively comparable [8].

In the framework of the European Virtual Observatory project (VESPA) [9] a FITS convention for planetary data will be proposed [10] following the WGCCRE schema.

Future work: In the coming months the new keywords to allow FITS to support planetary bodies will be defined and tested. Once the proposed geospatial extensions are fully agreed upon and added into FITS, the GDAL library will be updated to properly map these new keywords. To help contribute or follow updates to the GDAL FITS driver, please see: https://github.com/epn-vespa/gdal.

References:
[1] http://fits.gsfc.nasa.gov/fits_wcs.html. [2] http://www.gdal.org/gdal_vrttut.html. [3] Snyder, J. P. (1987) Professional paper: USGS, U.S. Government Printing Office. [4] Calabretta, M. R. and Greisen, E. W. (2002) A&A, 395:1077–1122. [5] Greisen, E. W. and Calabretta, M. R. (2002) A&A, 395:1061–1075. [6] Hare, T.M., et al. (2007), LPSC 39, abs #2536, [7] http://heasarc.gsfc.nasa.gov/fitsio/fitsio.html. [8] Archinal, B.A., et al. (2011), *Celestial Mechanics and Dynamical Astronomy*, 109, no. 2, Feb., 101-135, doi:10.1007/s10569-010-9320-4. [9] http://europlanet-vespa.eu/ [10] https://epn-vespa.github.io/geofits/.

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